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Pass actions, pass output, and storage organization in the Gier Algol 4 Compiler

ABSTRACT:

This report gives details of two important aspects of the Gier Algol 4 compiler:

1. Actions of the various passes; specifically the details of their interfaces.

2. Storage organization in the compiled program.

The report assumes that the reader is thoroughly familiar with Algol and in particular Gier Algol 4, and that he has some acquaintance with the operation of the compiler. It plunges immediately into technical details.

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I. The Tasks of the Passes

The best introduction to the design philosophy and overall operation of the compiler will be found in P. Naur, 'The Design of the GIER ALGOL Compiler', BIT 3 (1963), 124-140 and 145-166. Briefly, the compiler is divided into ten parts: the nine 'passes' and the 'General Pass Administration'. Pass 1 reads the source program and outputs to the backing store a series of 'bytes' which Pass 2 reads. Each of the following passes reads the output of the preceding pass and outputs a new sequence of bytes to be read by the next until finally Pass 8 outputs to the backing-store area 'work' the finished object program. (For historical reasons the pass named 'Pass 9' falls between Passes 6 and 7.)

We describe below the various parts of the compiler in greater detail. Appendix 2 gives the details of the interfaces between passes. Of course for the most detailed possible information about the compiler see the program listings, published by Regnecentralen as The Complete Annotated Programs of Gier Algol 4, 2 volumes, December 1967, GSL 494.

1. General Pass Administration (GPA). GPA is that part of the compiler which is common to all passes; it takes care of input and output of bytes, printing of error messages, and transition to the next pass.

The entry for output of a byte will, if wanted, print the byte as an integer. This check-out facility is a permanent part of the compiler. For details see the GA 4 Manual, section 13.4.

The entry for error message printing can identify the current place in the source program by printing the value of a common carriage return counter in front of the message. The carriage return counter is updated by all passes whenever they meet the carriage return byte in the input. Therefore this byte is carefully kept through all passes even when surrounding bytes are removed because of errors (see pass 3b and pass 4 below).

The first time GPA produces any printed output from a given pass it prints the pass number.

GPA contains a table which describes the successive passes of the compiler. This table is used during transition to a new pass.

The input and output of bytes is buffered so that the time used for drum transports during the execution of a pass is negligible.

2. Pass 1. Analysis and check of the hardware representation of the source program (micro structure). Conversion to reference language which is output as a stream of 10 bit bytes.

The input to pass 1 is the source program taken character by character from the input medium. The input medium may be paper tape, typewriter, magnetic tape, or a backing store area.

Besides the conversion to reference language, which also implies recognition of compound symbols, e.g. begin end if ≤ ≠ := , pass 1 performs several other tasks.

Comments and blind characters, e.g. blanks, are skipped.

Strings are packed in an internal representation.

Each n'th line of the source program may be printed.
Several non-Algol features related to the hardware representation are handled: Change of input medium, optional skipping of input between PUNCH OFF and PUNCH ON, check of character sum in the input, printing of messages to the operator, pause for insertion of new paper tape in the reader.

Pass 1 skips all input up to the first begin and terminates the processing when the corresponding end has been read.

3. Pass 2. Identifier matching.

Each identifier encountered in the input is searched for in an initially empty table in the core store. If not found the identifier is entered in the table. In any case it is output as one byte representing the serial number of the identifier in the table. The value is between 1021 and 512.

This matching is performed regardless of block structure. The generated table is kept in core for use by pass 3a after which it may be overwritten.

Pass 2 also assembles bit patterns, a non-Algol feature, and outputs them as logical values.

4. Pass 3a. Standard identifier matching.

The identifier table generated by pass 2 is searched for occurrences of standard identifiers, i.e. identifiers declared outside the source program.

Each occurrence gives rise to the output of two bytes: The serial number of the identifier in the list of standard identifiers followed by the byte representing the identifier in the pass 2 output.

5. Pass 3b. Analysis and check of delimiter structure (logical structure). Delimiters of multiple meaning are replaced by distinctive delimiters and extra delimiters may be added to facilitate the task for the following passes.

A sub-part of the logic analyzes numbers and converts them to internal machine representation which is then output as five byte constructions. Also the procedure headings are treated by a sub-part of the logic which checks for missing or double specifications and for not allowed value specifications. Furthermore the specifications are output as part of the list of formal parameters.

The main logic is performed by a finite state algorithm using a stack for holding encountered opening bracket delimiters, e.g. if begin ([.

The algorithm scans the input up to and including the next delimiter and sets the operand situation, i.e. the class of operand encountered during the scan for the delimiter.

The delimiter and the current state determine, via a matrix, the new state, and the specific delimiter meaning. This in turn determines the further actions, e.g. byte output, stacking, unstacking. Also the operand situation is checked for consistency with the delimiter.

In case of error a message is given and current state is set to a value which will insure skipping of the rest of the current construction, normally up to a semicolon or to an end.

6. Pass 4. (Backward scan): Collection of declarations at block begin.

Pass 4 stacks all declarations (labels are treated as declarations) and unstacks and outputs the top section of the stack whenever a BEGIN BLOCK byte is encountered in the input. However, to enable pass 5 to give a relevant line number in case of double declarations, the identifiers from the declarations are also transmitted to the output.

Pass 4 also counts the locations needed at run time:

In the whole program for:
- Display (= max block depth).
- Own variables.

In each block for:
- Simple variables, array descriptions, and dope vectors.
- Local declarations, i.e. the dynamic descriptions of labels and procedures.

In each procedure block furthermore for:
- Formal parameters.
- Dope vectors for formal arrays which in the procedure body appears with subscripts. (This enables the procedure entry to move the whole actual dope vector to local cells and thereby facilitate the subscription of the formal array.)

This last counting requires that all subscripted identifiers in a procedure body are stacked together with the number of subscripts. This stacked list is then confronted with the formal list from the procedure heading and the number of subscripts is added to the array specification.

Further pass 4 tasks:

Insertion of the bytes BYPASS LABEL and GOTO BYPASS LABEL which will enable pass 8 to generate jumps around procedure bodies.
Insertion of the byte WHILE LABEL in front of while elements in for-lists. Insertion of the byte PREPARE ASSIGN just after the last := in assignment statements.
Skipping of the rest of erroneous constructions found by pass 3b. As the last task, after having processed the first BEGIN BLOCK pass 4 initializes the pass 5 declaration table using the byte pairs generated in pass 3a; see pass 5.

7. Pass 5a. Storage allocation of variables. Distribution of identifier descriptions.

A table of identifier descriptions is built up, based on the declarations collected at block begin. This table is checked for double declarations by help of the identifiers left at the original place where the declaration occurred. All other occurrences of identifiers are in the output from pass 5 replaced by the description from the table.

The normal description will consist of three bytes:
< kind-type > < relative address > < block number >.
However, for a standard identifier only one byte is output. This byte refers to a table of descriptions which is built up by pass 5b, see below.

8. Pass 5b. Generation of standard identifier description table. Output of list of standard procedure code sections to be included.

A table containing the descriptions of those standard identifiers which actually have been used is built up in the top of core. This table will be used by pass 6 whenever a standard identifier is encountered in the input.

Finally pass 5b outputs a list of bytes specifying the standard procedure code segments to be included in the object program. This list is used by pass 8a.

9. Pass 6. Type checking (Global structure). Conversion to Reverse Polish Notation.

Based on a priority table for operators all expressions are converted to Reverse Polish Form. In parallel to this all kinds and types of operands are checked by means of a pseudo evaluation of the expressions. This process will also insert explicit type conversions when needed and will deliver the final type of more complicated expressions.

10. Pass 9 (between passes 6 and 7): This pass is an assembler. It interprets the text of code statements as machine code written in a subset of the SLIP assembly language. From here on each piece of user-specified machine code is taken as an indivisible sequence of machine words.

11. Pass 7. Generation of machine operations. Assignment of working locations.

By a simulation of the run time processes, with respect to where and how the operands are stored, pass 7 generates the machine code necessary to perform these processes, i.e. it determines the use of the machine registers and allocates run time working locations. However, as the internal references (jumps) can not be addressed yet, the output from pass 7 is still in the form of a byte stream.

12. Pass 8a. (Backward scan). Rearrangement of the pass 7 output on the drum. Loading of the standard procedure code sections specified in the list from pass 5b.

13. Pass 8b. Generation of final machine code including addressing of all internal references. Segmentation into backing store tracks.

14. Pass 8c. Loading of running system, i.e. the fixed set of administrative routines needed at run time.

Result of compilation: A self-contained object program stored on consecutive tracks on the drum. It is relocatable as a whole on the backing store.

II. Storage Organization

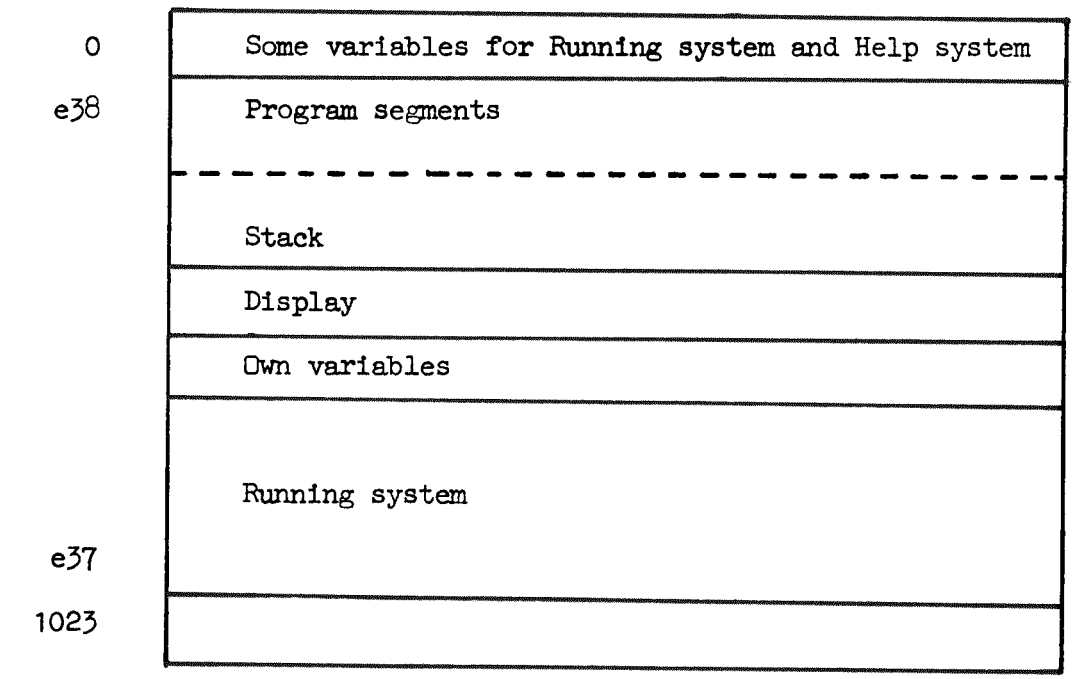
A compiled program, while it is running, makes use of three kinds of storage: the backing store (drum or disk), a core store of 1024 words, and possibly a 'buffer store' of 4096 words.

The backing store holds the entire compiled program (parts of which will also be found in core), the text of most string constants used in the program, and any files the program may explicitly make use of. (See A Manual of Gier Algol 4, section 11, for details of use of the backing store through explicit calls to standard procedures.)

Core store holds all the variables of the program (possibly excepting arrays), the running system, and some 'segments' of the program. For details of the program segmentation scheme see Naur, 'Features of the Gier Algol 4 System' Regnecentralen, November 1967).

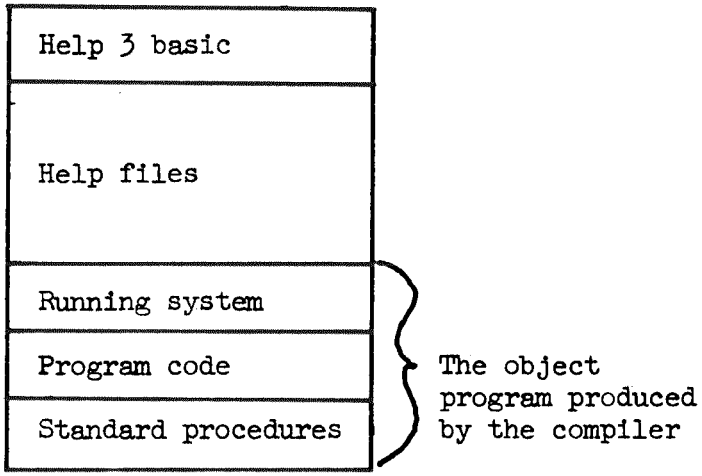
Buffer store, if available, holds all the array elements of the program. Figures 1 and 2 show the organization of core store and backing store during program execution.

Figure 1: Core Store During Program Execution



Normally e37 = 1022, e38 = 15.

Figure 2: Backing Store During Program Execution



Storage of Variables

Variables are in general kept in core as long as they are active, with the single exception that array elements are kept in the buffer store if one is available.

Storage for own variables is assigned by the compiler, and can be seen on the above diagram of core store, figure 1.

Storage for any other variable is assigned during execution at entry to the corresponding block and released at exit from the block. These 'local' variables are organized in a stack which grows and shrinks during execution of the program and competes with program segments for storage. The stack is not permitted to grow so large that there is room in core for less than four program segments.

Each incarnation of each block in the program has a single section in the stack. (Wherever the word 'block' appears in this paper we include any procedure body, whether or not it is a block in the usual sense of a begin ... end structure.) The block's stack section contains:

I In the case of procedure blocks, the formal locations for the procedure.

II The program points of the block.

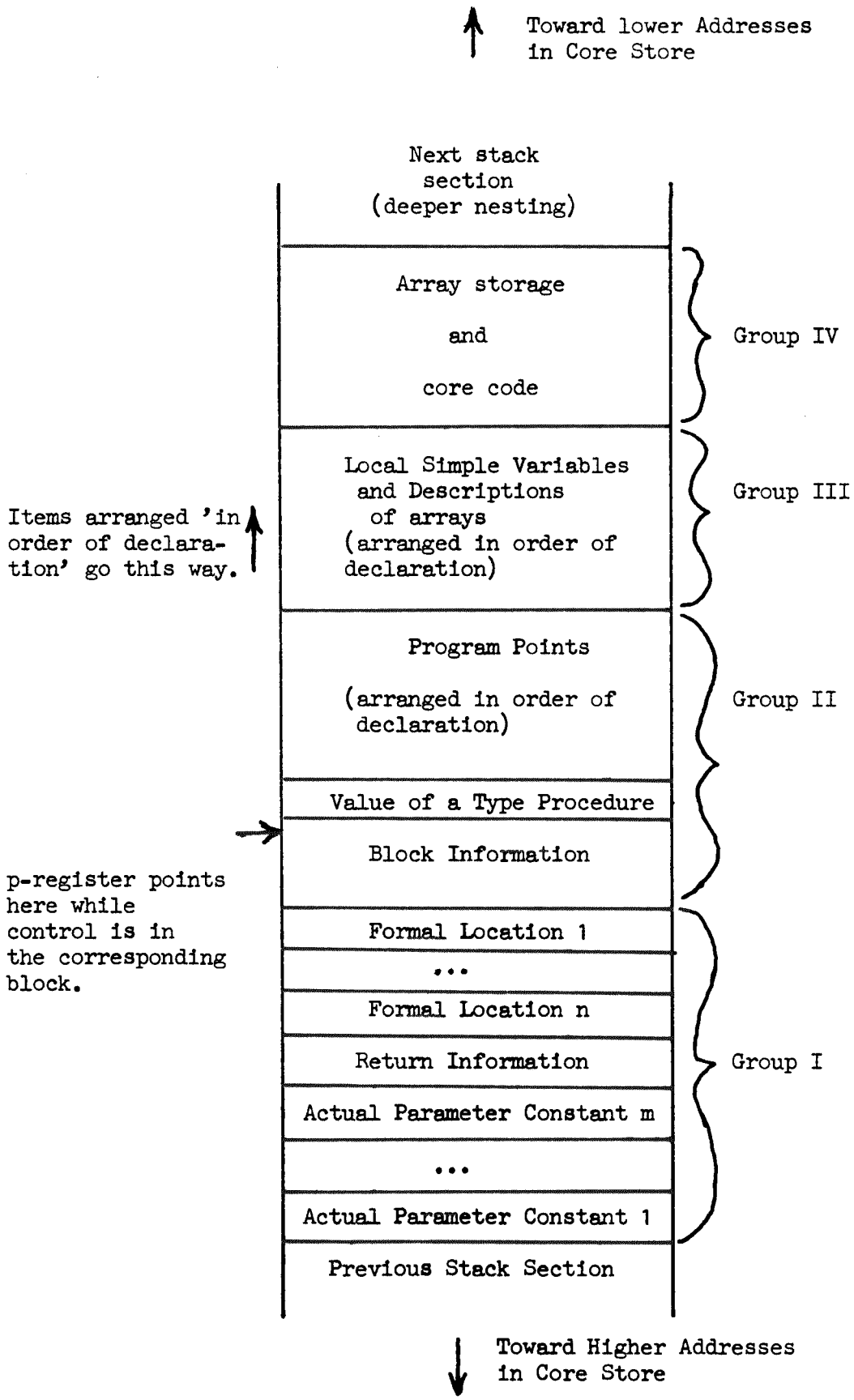
III The working locations and variables of the block.

IV Storage for arrays and for core code.

The numbering above corresponds to the common terminology of the 'groups' in a stack section. The diagram of figure 3 shows a stack section. We will go into the groups in some detail.

The 'display' is a list of pointers to stack sections. It is used for the purpose of allowing references within one block to variables in embracing blocks.

Figure 3: A Single Stack Section



Group I: The formal locations of a procedure block.

The machine code which the compiler produces for a procedure call works as follows:

1. Allocate storage for group I of the procedure block's section of the stack and create the 'block information' for that section.

2. Place into this stack section the return information and the formal words for the actual parameters of the call. The precise format of the return information and formal words is given in appendices 1.5 and 1.7. Suffice to say now that bits in the word may indicate among other things

   a. variable or constant
   b. program point
   c. 'thunk' - described below.

3. In addition place any constants referred to by these formal words into the stack section.

4. Set the p-register (which always indicates the current stack section) to point to the newly-created block information and transfer control to the procedure.

The procedure can now extend this stack section as necessary for its own storage, do its thing, and eventually return to its caller through the return information given. (At which time the p-register must of course be reset to point to the proper stack section.)

The 'thunk' is a device used to handle Algol's call-by-name convention. Its name has an obscure origin in the complex mind of Mr. Peter Z. Ingerman. If an actual parameter in a procedure call is an expression, and the corresponding formal parameter is 'by name' (that is, not declared value), then the expression must be re-evaluated every time the formal parameter is referred to in the procedure body.

A 'thunk' is a piece of code, organized somewhat like a procedure, which when invoked evaluates an actual parameter expression and places the address of the value in a standard location.

When the compiler compiles a call to a procedure it compiles a thunk for every actual parameter which is not a simple variable or constant. Then during execution, when the call is made, the call places a pointer to this thunk in the corresponding 'formal location' of the called procedure's stack section. Then a reference to the corresponding formal parameter consists of an invocation of the thunk.

In the case that the corresponding formal parameter is 'by value' rather than 'by name', thunks are not necessary but are used anyway. The actual parameter is evaluated immediately after entry to the procedure block and the value is stored in place of the formal word. Then access to this value is rather simple in the rest of the procedure.

Group II: The program points.

All labels and procedure entries are treated as local variables in the compiled code. Switches are treated as procedures, so they too must be considered here.

For each label and procedure entry in a block, a word is set aside in the stack section for the block and this word is initialized at block entry. (The format of the program point words is given in appendix 1.3.)

This convention means the compiler need not worry about the two basically different kinds of program point: Those available directly and those available by actual-formal correspondence. The formal location for a label or procedure formal parameter points to the program-point for it in the corresponding block.

Also generally included in Group II is the location set aside for the returned value of a type procedure. After the return from a type procedure as described above under Group I, the caller reaches up into the now-abandoned stack section of the procedure and picks up the returned value. After this has been done the contents of that stack section can be destroyed.

Group III: The working locations of the block.

Included in this group are all the simple variables of the program, and also descriptive information for arrays.

The descriptive information for an array is kept separate from the storage for the actual elements of the array for two reasons:

1. The storage for the array's elements must in the general case be allocated only after its limits are computed. Furthermore it may be that this storage is to be allocated in the buffer store and not in the stack. The descriptive information can keep a record of where this storage is allocated.

2. Because of efficiency considerations, descriptive information for array parameters of a procedure is copied into the stack section for the procedure at block entry.

See appendix 1.4 for the details of array descriptive information.

Group IV: Array elements and core code.

See A Manual of Gier Algol 4, section 12.7, for a discussion of core code. At entry to a block, all the pieces of core code declared in that block are copied into the stack section corresponding to the block. Then within the block they can be invoked through calls to the standard procedure gier.

At block entry the limits of arrays are evaluated, the storage is allocated for them, and appropriate information is inserted into the array descriptions mentioned in Group III. The storage allocated for arrays at this time will be in buffer store if it is available and in Group IV if not.

Storage allocated for arrays in the buffer store is assigned starting from the highest locations in the buffer and working downward.

A final use of the stack: Thunk returns. The call to a thunk is as follows:

1. Allocate one more word in the stack.

2. Place return information into this word.

3. Transfer to the body of the thunk.

After the thunk has done its evaluation, it returns by:

4. Release the topmost word of the stack.

5. Return control through this word.

It is necessary to use the stack for thunk returns because of two contingencies: The thunk may involve a call to a procedure; and it may involve a call to another thunk.

Storage of Constants

Each 'segment' of a program will contain a sequence of instructions plus all the ordinary constants which these instructions use. In most compilers it is worthwhile to group all the constants used in the program and eliminate duplications; but in Gier Algol 4, because of the segmentation scheme, such a grouping would decrease efficiency rather than increase it. No grouping of constants, therefore, is done except within individual segments.

The integer constants 0 and 1, and also any other constants with the same machine representation, are treated specially. The constant zero need never be kept in storage as instructions can do without it. The constant one is located in the running system and when needed is picked up there.

It is convenient to require that all actual parameters be continuously in core store. Therefore constant actual parameters are placed in the stack as described above in the discussion of Group I.

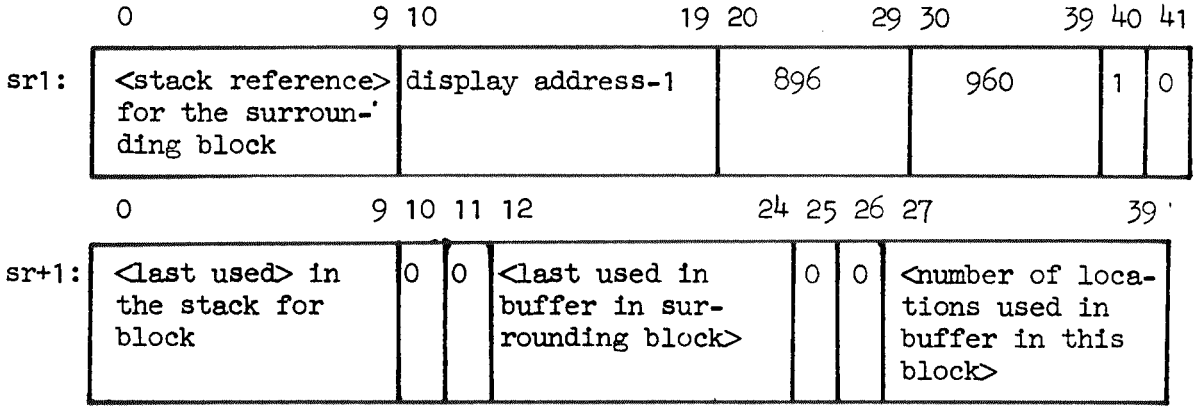
Strings are a little bit awkward because a string is the only kind of value that does not fit in a single word. Therefore the actual text of most strings (those longer than 6 characters) is kept on the backing store during program execution. See appendix 1.6 for a precise description of the format of strings in the machine; but here it suffices to say that when a 'string' is mentioned in connection with Gier Algol 4 implementation, the word usually means a single-word description of the string giving its location on the backing store.

A final form of constant is the layout. It is considered Boolean and its representation in storage is described in A Manual of Gier Algol 4, section 9.5.3.

Appendix 1: Details of storage formats

It will be noticed that many of these storage formats contain peculiar numerical constants in parts of various words. Generally such a constant turns a data word into an instruction or special indirect word; this makes various code optimizations possible. See appendix 2.9 for the ways in which the program store takes advantage of these storage formats.

1.1. Block information

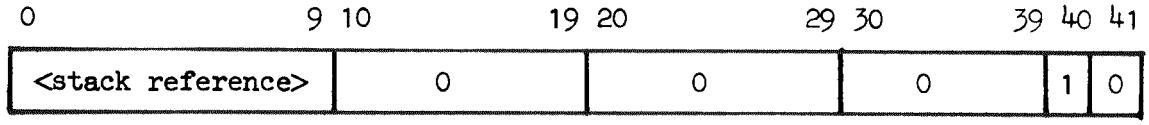


<stack reference> for the outermost block = 1.
<last used in buffer in surrounding block> at the beginning = 4096
<number of locations used in buffer in this block> before reservations in buffer = 0.

A procedure body is always considered to be a block. The surrounding block for a procedure is the block in which it is declared.

1.2. Value of type procedure

Until a value is assigned to a type procedure the contents of the location set aside for the procedure value is as follows:



1.3. Program point

(labels, switches, procedures)

		0 9	10 19	20 29	30 39	40	41
label		<sr> of the block where this label is local	relative address in track	0	track number	1 1	0 1
switch		ditto	ditto	40	ditto	1	0
procedure without parameters	no type	<sr>	ditto	24	ditto	1	1
	integer	ditto	ditto	488	ditto	1	0
	real	ditto	ditto	488	ditto	1	1
	Boolean	ditto	ditto	8	ditto	1	0
procedure with parameters	no type	ditto	ditto	24	ditto	1	1
	integer	ditto	ditto	16	ditto	1	0
	real	ditto	ditto	16	ditto	1	1
	Boolean	ditto	ditto	24	ditto	1	0

In the word for a label, bits 40-41 are 10 if the target is left-hand instruction in a word, and 11 if the target is the right-hand instruction.

1.4. Description of array

		0	9 10	19 20	29 30	39 40	41
Array word	arrays in core store	0	0	address of corner			
	arrays in buffer	c17	1	ditto			

bits 40-41: integer 00
real 01
Boolean 10

The 'corner' of an array is a hypothetical element with all subscripts zero (e.g. alpha[0, 0, 0, ...]).

The array word is followed by full-word integers giving lower bound 1, upper bound 1, lower bound 2, etc. These 'bound words' appear regardless of whether index checking was specified in the compilation.

1.5. Formal location

		0	9 10	19 20	29 30	39 40	41
Constants	integer	c30	absolute address	520	0	0	0
	real	c30	ditto	520	0	0	1
	Boolean	c30	ditto	520	8	0	0
	string x)	c30	ditto	520	8	0	1

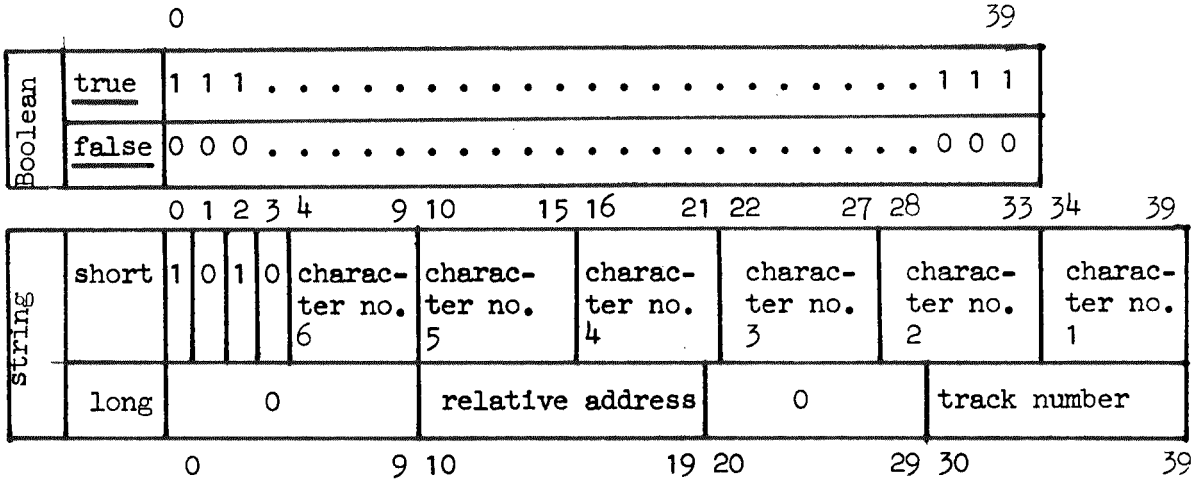
		0 – 9	10 – 19	20 – 29	30 – 39	40	41	
Simple variables	integer	c30	absolute address	512	0	0	0	Absolute addresses of constants label descr. and simple variables
	real	c30	ditto	512	0	0	1	
	Boolean	c30	ditto	512	8	0	0	
	string ×)	c30	ditto	520	8	0	1	
	label	c30	ditto	512	8	0	1	
Subscripted variable	integer	stack reference for block containing the expression	relative address in track	480	track number	1	0	program points for thunks ××)
	real	ditto	ditto	480	ditto	1	1	
	Boolean	ditto	ditto	0	ditto	1	0	
Other expressions	integer	ditto	ditto	488	ditto	1	0	
	real	ditto	ditto	488	ditto	1	1	
	Boolean	ditto	ditto	8	ditto	1	0	
	string	ditto	ditto	8	ditto	1	1	
	label	ditto	ditto	0	ditto	1	1	

×) The address of a string is: for a short string, the address of a word containing the string; for a long string, the address of a drum point description (see Appendix 1.6, below).

××) Where a formal is declared value, the formal location is also used to store the value computed at block entry.

		0 – 9	10 – 19	20 – 29	30 – 39	40	41
array		address of ray word-1	dope address -addr of array word-2	0	<number of subscripts + 1>	0	0
Switch and procedure ident. other than expression	integer	stack reference for block where declared	relative address in track	16	track number	1	0
	real	ditto	ditto	16	ditto	1	1
	Boolean	ditto	ditto	24	ditto	1	0
	no type	ditto	ditto	24	ditto	1	1
	switch	ditto	ditto	40	ditto	1	0

1.6. Constants



One word of a long string on the backing store:

	0 1 2 3 4 – 9	10 – 15	16 – 21	22 – 27	28 – 33	34 – 39
not last	1 1 1 1	character	character	character	character	character
last	1 0 1 0	no. 6	no. 5	no. 4	no. 3	no. 2	no. 1

Integer and real constants take their 'natural' machine representations.

1.7. Return information

0 – 9	10 – 19	20 – 29	30 – 39	40	41
for procedures	stack reference for return point	<track rel. address>	40	track number	1 1	1 0
for thunks	ditto	ditto	880	ditto	1	0

1.8. Block information

	0 – 9	10 – 19	20 – 29	30 – 39	40	41
sr:	sr for surrounding block	display address - 1	896	960	1	0

	0 – 9	10	11	12 – 24	25	26	27 – 39
sr+1:	last used in core store	0	0	last used in buffer in surrounding block	0	0	number of locations used in buffer in this block

<sr for the surrounding block> for the outermost block = 1
<last used in buffer in surrounding block> in the beginning = 4096
<number of locations used in buffer in this block> before reservations in buffer = 0.

Appendix 2: Details of pass output

2.1. Pass 1

The three columns give: (1) the output byte value, (2) the meaning, and (3) the pass where the value is processed.

1	a	2	37	I	2	93	begin	3	267	×	3
2	b	2	38	J	2	98	for	3	268	/	3
3	c	2	39	K	2	106	if	3	269	↑	3
4	d	2	40	L	2	109	own	3	270	:	3
5	e	2	41	M	2	116	integer	3	271	≤	3
6	f	2	42	N	2	123	real	3	272	<	3
7	g	2	43	O	2	130	boolean	3	273	=	3
8	h	2	44	P	2	137	procedure	3	274	>	3
9	i	2	45	Q	2	144	array	3	275	≥	3
10	j	2	46	R	2	149	switch	3	276	≠	3
11	k	2	47	S	2	153	string	3	277	∧	3
12	l	2	48	T	2	155	label	3	278	∨	3
13	m	2	49	U	2	157	value	3	279	=	3
14	n	2	50	V	2	167	;	3	280	⇒	3
15	o	2	51	W	2	172	end	3	281	mod	3
16	p	2	52	X	2	176	else	3	282	shift	3
17	q	2	53	Y	2	184	(	3	287	)<let>:(	3
18	r	2	54	Z	2	194	: or ,[x]	3	291	)	3
19	s	2	55	Æ	2	196	step	3		<code>	
20	t	2	56	Ø	2	198	until	3	1008	-begcode	3
21	u	2	57	0	2,3	200	while	3	1009	end pass	2
22	v	2	58	1	2,3	202	]	3	1010	CAR RET	2
23	w	2	59	2	2,3	210	[	3		<4 bytes>	
24	x	2	60	3	2,3	220	, or :[x]	3	1011	-short str	2
25	y	2	61	4	2,3	228	:=	3	1012	-long str	2
26	z	2	62	5	2,3	231	then	3	1013	-layout	2
27	æ	2	63	6	2,3	243	do	3	1014	0	2
28	ø	2	64	7	2,3	245	abs	3	1015	1	2
29	A	2	65	8	2,3	249	code	3	1016	2	2
30	B	2	66	9	2,3	251	core	3	1017	3	2
31	C	2	67	.	3	256	case	3	1018	4	2
32	D	2	68	␣	3	258	of	3	1019	5	2
33	E	2	72	+	3	260	round	3	1020	6	2
34	F	2	76	-	3	262	entier	3	1021	7	2
35	G	2	82	-,	3	265	true	3	1022	8	2
36	H	2	86	go to	3	266	false	3	1023	9	2

[x]) Between 249 code and the first following 1008 begcode.

<code> ::= <any number of bytes between 0 and 511>
<1024 - number of CAR RET within the machine code>
The code of the machine language representation is given in appendix 2.7.

Output byte value 1009 end pass will appear at the very end of the output from pass 1 in the following context:

... 172 1009 0
<4 bytes> ::= <short text>|<text on drum>|<layout>
<text on drum> ::= 0 <track relative> 0 <track number>
<layout> ::= <layout bits 0 - 9><layout bits 10 - 19>
<layout bits 20 - 29><layout bits 30 - 39>

2.2. Pass 2

The three columns give: (1) the output byte value, (2) the meaning

57 0	137 procedure	<code>
58 1	144 array	264-beg code
59 2	149 switch	265 true
60 3	153 string	266 false
61 4	155 label	267 ×
62 5	157 value	268 /
63 6	167 ;	269 ↑
64 7	172 end	270 :
65 8	176 else	271 ≤
66 9	184 (	272 <
67 .	194 : or ,[x]	273 =
68 ␣	196 step	274 >
72 +	198 until	275 ≥
76 -	200 while	276 ≠
77 CARRET	202]	277 ∧
78 <4 bytes> short str	210 [	278 ∨
79 <4 bytes> long str	220 , or :[x]	279 ≡
80 <4 bytes> Boolean lit	228 :=	280 ⇒
82 -,	231 then	281 mod
86 go to	243 do	282 shift
93 begin	245 abs	283 end pass
98 for	249 code	287)<let>:(
106 if	251 core	291)
109 own	256 case	
116 integer	258 of	512-1021
123 real	260 round	Identifiers
130 boolean	262 entier	

[x]) Between 249 code and the first following 264 begin code.

<code> ::= <any number of bytes between 0 and 511>
<1024 - number of CAR RET within the machine code>
The code of the machine language representation is given in appendix 2.7.

Output byte value 283 end pass will appear at the very end of the output from pass 2 in the following context:
... 172 283 0

<4 bytes> is explained in appendix 2.1.

2.3. Pass 3

The output from pass 3 is scanned in the reverse direction by pass 4. This must be remembered when interpreting the structure.

The first part of the output has the structure:

0 <standard identifier pair list><identifier limit> 20

with

<standard identifier pair> ::= <standard identifier no><identifier>

The remaining bytes are coded as follows:

	0	CAR RET	<i>	56	spec label	154	code
<4>	1f	literal	<i>	57f	spec value	155	end switch
<4>	4	literal string	<i>	60f	spec array	156	and
<il>	5f	decl simple	<i>	63	spec proc no	157	or
	8	decl label	<i>	64f	spec proc	158	imply
<il>	9f	decl own	<i>	67	spec switch	159	=
<il>	12f	decl array	<i>	68	spec undef	160	↑
	15	end clean	<i>	69	spec general	161	)
	16	end block		70	simple for element	162	simple for do
	17	end bounds		71	:= for	163	step element do
<no. of parameters>				72	step element	164	while element do
-	18	end proc no type		73	while element	165	case st
-	19	end type proc		74	while	166	case expr
-	20	begin		75	end assign	167	of expr
	21	;		76	:=	168	end case expr
	22	do		77	first:=	169	case comma
	23	then statement		128	proc;	170	case semicolon
	24	else statement		129	ifex	171	end loop
	25	of statement		130	ifst	492	<
	26	end case statement		131	thenex	493	≤
<code>				132	elseex	494	=
-	27	code end		133	delete call	495	>
	28	core		134	end else ex	496	≥
	29	core code end		135	end else st	497	≠
	30	end spec		136	end then st	500	-,
	31	end call		137	end go to	501	entier
	32	] one		138	for	504	pos
	33	] more		139	step	505	neg
	34	call parameter		140	until	506	abs
	35	comma 1		141	end do	507	round
	36	comma 2		142	end single do	508	opint
	37	bound colon		143	mod	509	opreal
	38	begin call		144	+	510	opbool
	39	begin function		145	-	511	opstring
	40	left bracket		146	×	512-1021	
	41	trouble		147	/		identifiers
<i>	42	decl parproc no		148	:	999	begin code
<i>	43f	decl par proc		149	↑	1022	internal identifier
<i>	46	decl switch		150	shift		
<i>	47	decl proc no par		151	first bound		
<i>	48f	decl proc no par		152	not first bound		
<i>	51	decl undef proc		153	of switch		
<i>	52f	spec simple					
<i>	55	spec string					

<4> ::= <bits 0 - 9><bits 10 - 19><bits 20 - 29><bits 30 - 39>

<i> ::= <identifier, i.e. byte in range from 512 to 1021>

<il> ::= <i>|<il><i>

<code> is explained in appendix 2.7.

f indicates that three consecutive byte values describe types: +0 = integer, +1 = real, +2 = Boolean.

2.4. Pass 4

```
     0  CARRET
<base w><base var>
- -  1  begin block
     2  end pass
<no of actuals>
-    3  begin func
<reverse code>
-    4  begin code
     5  end core code
<i>  6  decl switch
<i>  7  decl label
<i>  8  decl proc err
     9  formal label
    10  formal general
    11  formal unspec
    12  core store
    13  formal switch
    14  end bounds
    15  end head
    16  end decl
    17  end block
<no.of parameters>
-   18  end proc
-   19  end type proc
<spec list>
-   20  specifications x)
<i> 21  label colon
<no of actuals>
-   22  begin call
<no of subscripts>
-   23  [
    24  end bound head
<i> 28f begin bounds
<base w><base var>
- - 35  begin switch
- - 36  begin par proc
- - 37f beg par proc type
- - 40  beg no par proc
- - 41f beg no par proc type
<i> 44f decl no par proc
<i> 47  decl no par proc
<i> 48f decl par proc x)
<i> 51  decl par proc x)
<i> 52f decl simple
<i> 56f decl own
<no of subscripts>
-   60f decl array
-   64f take array
<i> 68f take value
<i> 72f formal proc
    75  formal proc
<i>  76f formal simple
<i>  79  formal string
<i>  80f anon. array
<4>  84f literal
<4>  87  literal string
    128  proc;
    129  if expression
    130  if statement
    131  then expr
    132  else expr
    133  delete call
    134  end else expr
    135  end else stat
    136  end then stat
    137  end go to
    138  for
    139  step
    140  until
    141  end do
    142  end single do
    143  mod
    144  +
    145  -
    146  ×
    147  /
    148  :
    149  ↑
    150  shift
    151  first bound
    152  not first bound
    153  of switch
    154  code
    155  end switch
    156  and
    157  or
    158  imply
    159  =
    160  ⌜
    161  )
    162  simple for do
    163  step elem do
    164  while elem do
    165  case stat
    166  case expr
    167  of expr
    168  end case expr
    169  case comma
    170  case semicolon
    171  end loop
    172  do
    173  then stat
    174  else stat
    175  of stat
    176  end case stat
    177  end call
    178  ] one
    179  ] more
    180  call param
    181  comma 1
    182  comma 2
    183  bound colon
    184  simple for
    185  := form
    186  step element
    187  while element
    188  while
    189  end assign
    190  :=
    191  first:=
    192  while label
    193  prep assign
    194  go to bypasslabel
    195  bypasslabel
    492
    493  ≤
    494  ≡
    495
    496  ¬
    497  ≠
    500  not -,
    501  entier
    504  positive
    505  negative
    506  abs
    507  round
    508  op.integer
    509  op.real
    510  op.boolean
    511  op.string
    512 - 1022
         identifiers
         Specifications x)
   1006  general
   1007  undecl
   1008   switch
   1009g  proc type
   1012   proc no type
   1013g  array
   1016g  value
   1019   label
   1020   string
   1021g  name
```

f and g indicate that three consecutive byte values describe types:
f: +0=integer, +1=real, +2=Boolean. g: +0=Boolean, +1=real, +2=integer
<4> ::= <bits 30-39><bits 20-29><bits 10-19><bits 0-9>

x) The declaration of a procedure with parameters or a switch (treated as a procedure having one integer value parameter) appears in the block head as:
<identifier><decl par proc><spec list> 20

<base w> ::= 1024 - number of locations used for local variables
- number of locations used for program points
<base var> ::= 1024 - number of locations used for local program points
<spec list> ::= <specification, i.e. byte between 1006 and 1023>|
<spec list><specification>

The last bytes appearing in the output refer to the outermost block and the entire program and are:

1. <base w> of outermost block
2. <base var> of outermost block
3. identifier limit = smallest identifier byte - 1
4. standard identifier having lowest standard identifier number in output from pass 3.
5. 1021 - maximum block number - number of owns
6. 2 + number of owns
7. 0

2.5. Pass 5

128 proc;
129 ifex
130 ifst
131 thenex
132 elseex
133 delete call
134 end else ex
135 end else st
136 end then st
137 end go to
138 for
139 step
140 until
141 end do
142 end single do
143 mod
144 +
145 -
146 ×
147 /
148 :
149 ↑
150 shift
151 first bound
152 not first bound
153 of switch
154 code
155 end switch
156 and
157 or
158 imply
159 =
160 (
161)
162 simple for do
163 step element do
164 while element do
165 case st
166 case expr
167 of expr
168 end case expr
169 case comma
170 case semicolon
171 end loop
172 do
173 then st
174 else st
175 of st
176 end case st
177 end call
178] one
179] more
180 call param
181 comma 1
182 comma 2
183 bound colon
184 simple for
185 := for
186 step element
187 while element
188 while
189 end assign
190 :=
191 first:=
192 while label
193 prep ass
194 goto bypasslabel
195 bypasslabel
196 CAR RET
<working base>
197 - begin block
<proc.type><working base>
198 - - begin proc
<no of subscripts>
<dope rel>
199 - - take array
200f take value
203 end bounds
204 end block
<no of formals>
205 - end proc no type
206 - end proc type
207 label colon
<no.of actuals>
208 - begin call
<no.of subscripts>
209 - [
<the code><-no.of CR>
210 - - begin code
211 end come code
212 core code
<track list> 0
213 - - end pass
<no. of actuals>
214 - begin func
<rel.adr.coef><no.arr.>
<array type>
215 --- begin bounds
<block address>
412 - formal general
416 - undeclared
420 - label
424 - switch
428 - formal label
432 - formal switch
436f- no par proc
439 - no par proc no type
440f- par proc
443 - par proc no type
int,real,bool,not
444f- simple
448f- array
<dope relative><-no of subs.>
452- -dope description
<block address>
456f- formal procedure
459 - formal proc.no type
460f- formal simple
463 - formal string
464f- anonymous array
<4 bytes>
468f- literal
471 - literal string
Specifications
472f spec simple
475 spec string
476 spec label
477f spec value
480f spec array
483 spec proc no type
484f spec proc
487 spec switch
488 spec unspec
489 spec general
492 <
493 ≤
494 =
495 >
496 ≥
497 ≠
500 not -,
501 entier
504 pos
505 neg
506 abs
507 round
508 opint
509 opreal
510 opbool
511 opstring
512-1023 stdproc

First byte in output
1021 - maximum block number - number of owns.

Array declarations
    id1
    id2
     •
     •
     •
    idn
    const
    length
    coeff
rel adr of length
no of arrays
array type 1: integer, 2: real, 3: boolean
proc type 0: no type, 1: integer, 2: real, 3: boolean
          with par 1023: boolean, 1022: real, 1021: integer, 1020: no type
          1019: switch
<block address> ::= <rel adr><block no>

Specifications appear following each parameter procedure identifier in the reverse order of the original formal parameter.

Byte 213, end pass, is followed by:
1. 1 + number of standard procedure tracks used.
2. 1021 - maximum block number - number of owns.
3. A list of the standard procedure tracks needed.
4. 0.

f indicates that three consecutive byte values describe types: +0 = integer, +1 = real, +2 = Boolean.

2.6. Pass 6

```
0       begin call
1       end call
 <type><working base>
2 - -   begin proc
 <no.of formals>
3 -     end proc
4 -     end type proc
 <working base>
5 -     begin block
6       end block
7       go to bypasslabel
8       label decl
9       while label
10      if
11      else st
12      end else st
13      for
14      := for
15/527  simple for
16/528  simple for do
17/529  while
18      while element
19      while element do
20/532  step
21/533  until
22/534  step element
23/535  step element do
24      end do
25      first subscript
26      not first subscript
27      not last subscript
28      last subscript
  /541  round top
        float top
        float next top
32/544  abs
  /545  entier
34      -,
35/547  negative
36      proc;

  <type of expr>
37/549- else Rt expr
38    - else addr expr
39/551- end else Rt expr
40    - end else addr ex
41      then
42      prepare assign
43/555  :=
44      go to
45/557  +
46/558  -
47      integer multiply
  /560  real multiply
  /r61  /
50      :
51      mod
52      ↑ integer
  /565  ↑ real
54/566  < then
55/567  ≤ then
56/568  = then
57/569  > then
58/570  ≥ then
59/571  ≠ then
60/572  <
61/573  ≤
62/574  =
63/575  ≥
64/576  >
65/577  ≠
66      ∧ and
67      ∨ or
68      =
  <bl.rel><bl.no>
69 - -   label
  <bl.rel.><bl.no>
   <sl.rel.dope>
   <-no of subsc>
70 ---   array
71 - -   simple
72 - -   formal
73 - -   procedure
  <tr.no><tr.rel.>
74 - -   std.  proc
  <4 bytes>
75  -    constant
76       end switch call
77       end single do
  <type>
78/590 - param comma
  <bl.rel.of dope>
  <no. of arrays>
  <array type>
79 - -   begin bounds
80       first bound
81       not first bound
82       end bounds
83       take real value
84       take int value
  <no.of subs.><array rel>
85 - -   take array
86       bypasslabel
  <stack ref 0 + 2>
  <no.of table bytes>
  <std.track tab.bytes>
87 ---   end pass
88       outchar
89       lyn
90       kbon
91       shift
92       select
93       opreal
94       opintrestr
95       gier
96       CAR RET
97       case
98       begin case
  <type>
 99/611- caseparam
100      casest
  <total type>
101/612  end case
102  5   end address case
103      end stat case
  <no of groups>
  <5-bytes groups>
104 - -  code
105      begin switch case
106      take nonsense
107      std 2 call
108      array param
109/621  move value
110      move address
111      move short
112/624  first value
113      first address
114      first short
115      new track
116      address

150      core
151      code
152      begin code
```

2.7. Machine language in output from passes 1 - 6

The representation of machine language is copied without change through passes 2 to 6, using the code given below. Because pass 4 scans its input in reverse order, the bytes will appear in the output from that pass in the reverse order.

1 K	28 -	55 g
2 L	29 +	56 h
3 M	30 ,	57 i
4 N	31 (	58 j
5 O	32 <illegal>	<4 text bytes>
6 P	33 k	59 - not last
7 Q	34 l	text word
8 R	35 m	60 - last text
9 S	36 n	word
10 T	37 o	61 m
11 U	38 p	62 $\overline{\text{I}}$
12 V	39 q	63 $\overline{\text{C}}$AR RET
13 W	40 r	64 0
14 X	41 s	65 1
15 Y	42 t	66 2
16 Z	43 u	67 3
17 A	44 v	68 4
18 B	45 w	69 5
19 C	46 x	70 6
20 D	47 y	71 7
21 E	48 z	72 8
22 F	49 a	73 9
23 G	50 b	74 :
24 H	51 c	75 =
25 I	52 d	76 blind CAR RET
26 J	53 e	77 e
27 .	54 f	78 $\overline{\text{J}}$

<4 text bytes> ::= <bits 4 to 12><bits 13 to 21>
<bits 22 to 30><bits 31 to 39>

<code> ::= <a sequence of the above byte structures except 77>
77 <1024 - number of CAR RET within the machine language code>

<reverse code> ::= <code written in the reverse order>

2.8. Pass 7

```
<blockrel>
-    0 addr local
-    1 var local
-    2 var abs
<blockrel><-blockno>
- -  3 var block
     4 (UA)
<UVrel>
-    5 UV
<trackno><trackrel>
- -  6 std proc call
<blockrel><-blockno>
- -  7 begin call
<bits 30-39>...<0-9>
----  8 constant
<trackno><trackrel>
- -  9 std 2 call
    10 begin block
<proc type>
-   11 begin proc
    12 begin case
    13 begin sw case
<no of lits>
-   14 end call
<case type>
-   15 527 end case
<appetite><-blockno>
- - 16      end proc
- - 17      end typeproc
- - 18      end block
<param inf><kind><type>
--- 19 531 call param
--- 20 532 case param
    21      if/for
    22 534 hop NT
    23 535 hop LT
    24 536 hop NZ
    25 537 hop LZ
    26 538 bypass abs
    27 539 bypass NT
    28 540 bypass LT
    29 541 do abs
    30 542 goto bypass
    31 543 bypasslabel
<type>
-   32 544 else
-   33 545 end else
<opand>
-   34      enddo
-   35      end single do
-   36 548 take forlabel
    37 549 formal assign
    38 550 take real val
    39 551 take int val
```

```
<no of indic><doperel>
--40 552 move array
  41     writecr
  42     goto computed
  43     select 1
  44     select 2
  45     tk 1
  46     lyn
  47     kbon
  48     hs mult X NZA
  49 561 mt -1 D NT
  50     il 0
  51 563 mt -1 D LT
  52     us 0
  53 565 mt neg
  54     sr eps
  55     srf half
  56     pm UV
  57     pm UA
  58     arn UA
  59     ga UA
  60     outchar var
  61     ck (addr)
  62     tk 30
  63 575 ck -10
  64     int to address
  65     ab 0 DX
  66     ar eps LT
  67     xr
  68 580 tkf -29
  69     nkf 39
<opand>
- 70 582 pm
- 71 583 gm
- 72 584 mkf
- 73 585 dkf
- 74 586 qq
- 75 587 mt
- 76 588 snn
- 77 589 ann
- 78     mb
- 79     ab
- 80 592 grn
- 81     dln
- 82     ann X
- 83     dln X
- 84     sr LT
- 85 597 hs
- 86 598 pm D
- 87 599 arn D
- 88 600 ar D
- 89     gr MA
- 90     gr MB
- 91 603 gm M
```

```
<opand>
- 92 604 grn M
- 93     mln X IZA
- 94 606 acn MA
- 95     mb X
- 96     reserve array
- 97 609 var to UA
- 98     goto local
- 99     index upper
- 100    index lower
- 101 613 move formal
- 102 614 take formal
- 103 615 contr. formal
- 104 616 take assign

 <address constant>
- 106    ck
- 108    outchar const

<no of formals>
- 109    ps p
  110    label declar
  111 623 real
  112    carret
  113 625 int
<5 byte words><no words>
---114   code

  115    newtrack
  116    end pass
```

```
<opand>:
- 121 633 arnt
- 122 634 art
- 123 635 srt
- 124 636 grt
- 125 637 srnt
- 126 638 annt
- 127 639 grt M
- 128 640 grt V LA
```

```
<type>:
1019 label proc
1020 no type
1021 integer
1022 real
1023 boolean
   0 no type
   1 integer
   2 real
   3 boolean
   4 string
   5 label
```

```
<kind>:
2 subscr
3 statement
4 UA-expr
5 expr
6 stdproc
7 descr
8 constant
9 simple
10 array
```

2.9. Pass 8

Remarks on the notation:
The word 'program' will refer to the generated machine code.

The signs ✱ and ⊕ on instructions indicates that they are generated only in the buffer-mode or core-mode respectively.

Entry points in running system (RS) are referred to by their Slip-names i.e. c0, c1, c2, etc. For details of the running system see Asmussen, et al, 'Gier Algol 4 Library Procedures' Regnecentralen Sept. 1967, Order no. 470.

The indications -->[ref] and [ref]<-- mean that the actual instruction appears in the program immediately before or after (respectively) the instruction referred to in the brackets.

2.9.1. Segmentation

The output from pass 8 - the final machine code - is generated into segments of 40 GIER words corresponding to a backing store track. The tracks will be referred to by a relative negative number using the term <trackno>. The range of <trackno> depends on the number of standard procedure tracks used and on the size of the program.

A word on a track is referred to by a relative address ranging from 0-39 using the term <trackrel>.

Each track consists of three parts:
1) A number of words from <trackrel> = 0 and onwards containing literal constants (see ref. a7) or special jump instructions (see section 5) referred to from
2) the proper machine code which is located after possible constants until and including <trackrel> = 38.
3) In <trackrel> = 39 an exit-to-next-track instruction (ref. j7-8) or in case of the last track of the program an exit-program instruction (j17).

2.9.2. Operand addressing

Machine instructions referring to runtime locations of operands will be referred to here by the term <op> in the address part.

<op> covers the following possible ways of addressing.

ref.:	address part		meaning	dir.byte
[a1]	(p<blockrel>)	:	address in local block	0
[a2]	p<blockrel>	:	variable in local block	1
[a3]	<abs addr>	:	variable in outermost block	2
[a4]	s<blockrel>	:	variable in intermediate block	3
[a5]	(c30)	:	address in UA	4
[a6]	c17	:	UV	5
[a7]	r<rel addr>	:	constant operand on actual track	8

where:
<blockrel> = value generated in pass 7 for the corresponding variable
<absaddr> = c0+<blockrel>
<reladdr> = <trackrel of word referred to>
- <trackrel of current instruction>

The value of the p-register will at run time always be equal to the stackreference of the current block, while the s-register is set by the instruction [a8] below, which is generated in an undefined place on the current track before the variable-reference [a4] but after the last:

a) program point (see below)
b) reference to a variable in another intermediate block
c) place where s is destroyed (eg. through an entry in RS)

[a8] ps(<displ ref>)

where:

<displ ref> ::= c0-<blockno>

2.9.3. Independently generated half- or full-word instructions

The following instructions are generated independent of the surrounding input structure, direct on a corresponding directing byte. For instructions i1-29 and f1-8 this is performed in connection with following operand-bytes, for instructions c1-25 without.

The instructions f1-8 may appear in the program with an f-mark if <op> represents a real operand. This is indicated to pass 8 through the bytes ranging from 533-541.

A number of further instructions which could be classified as belonging to this section are described in section 5.

ref.	instruction				meaning / used in	caused by dir. byte
i1	pm	<op>			a:= b, array declarations	70
i2	gm	<->			- , -	71
i3	mkf	<->			×	72
i4	dkf	<->			/	73
i5	qq	<->			assign to formal variable	74
i6	mt	<->			:, mod, step var until	75
i7	snn	<->			op ≠ 0	76
i8	ann	<->			op = 0	77
i9	mb	<->			∧	78
i10	ab	<->			∨	79
i11	grn	<->			op:= 0;	80
i12	dln	<->			:	81
i13	ann	<->	X		:, mod	82
i14	dln	<->	X		mod	83
i15	sr	<->		LT	mod	84
i16	hs	<->			gier(op)	85
i17	pm	<->	D		parameter to fast std.proc	86
i18	arn	<->	D		-	87
i19	ar	<->	D		-	88
i20	gr	<->		MA	declare boolean array	89
i21	gr	<->		MB	declare real array	90
i22	gm	<->		M	initialize step element [i1]<--	91
i23	grn	<->		M	- - -	92
i24	mln	<->	X	IZA	-->[j18]	93
i25	acn	<->		MA	step (first time)	94
i26	mb	<->	X		=	95

ref.	instruction		meaning / used in	caused by dir. byte
i27	gm p<blockrel> MA		set jumpword to forlabel left	36
i28	gm p< - > MC		- - - - right	36
i29	ck <10 bit const>		shift <constant>	106
f1	arn <op>		a+op, op-a, a×op, ...	121,533
f2	ar <->		op+a	122,534
f3	sr <->		a-op	123,535
f4	gr <->		op:=	124,536
f5	srn <->		-, op	125,537
f6	ann <->		abs op	126,538
f7	gr <->	M	initialize step, decl int.array	127,539
f8	gr <->	V LA	step (not first time)	128 540
c1	tk 1		<boolean expr> then	45
c2	mt-1	D NT	a ≠ b	49
c3	mt-1	D LT	a = b	50
c4	il		A[i], buffer version	51
c5	us		- , -	52
c6	mt c44		expr > a, a < expr	53
c7	sr c41		≤ , = , ≥	54
c8	srf c43		entier	55
c9	pm c17		var:= A[i], buffer version	56
c10	pm c30		for formal var:=	57
c11	arn c30		formal var parameter to fast std.	58
c12	ga c30		A[i], as actual parameter	59
c13	ck (c33)		shift var	61
c14	tk 30		A[i], no check, core version	62
c15	ck -10		A[i], check; shift var	63
c16	ga c33		shift var [c15]<--	64
c17	ab	DX	-, =	65
c18	ar c41	LT	:	66
c19	xr		A[i, j ...	67
c20	tkf -29		round real	68
c21	nkf 39		float integer	69
c22	pmf c55 , ga c55		select -->[c23]	43
c23	tln 9 , ud c55		- [c22]<--	44
c24	ps p + 2 + nform		prepare exit proc -->[j14-15]	109
c25	qq (c35) t nconst		adjust last used after call	14

nform = number of formals
nconst = number of constant formals

2.9.4. Multiple generated instructions

Each of the following instruction-groups is generated on a single directing byte with possible operands.

m1	srn c41	kbon	47
	qqn NKB		
m2	arnf (c30) V LB	take real value	38
	abn (c30) , nkf-39		
m3	arn (c30) V NB	take integer value	39
	arnf (c30) , tkf-29		

Ref.	instruction	meaning / used in	caused by dir. byte
m4	ck-10 , nc 1+<no of ind> pt c49-5 , hs c27 ga c33 , it p-3+<array rel> pa c30 , tk 10 gr c17 M pm (c17) t 1 IRC gm (c30) t 1 MRC udn c17 NZ bt (c33) t - 1 hv r-4	move array description	40
m5	ps <op> hv c2	goto local	98
m6	it <op> pa c30	variable to UA	97
m7	arn <op> V LT pt c49-5 , hs c27	index upper, check mode	99
m8	sr <op> V NT pt c49-5 , hs c27	index lower, check mode	100
m9	srn <op> , hs c20 ⊕ arn c35 , hv s2 ⊕ ck 10 ⊕	reserve array (core mode)	96

2.9.5. Program points, jumps and exits to RS

Program points are entries in the program which are referred to from other places. They may be explicit caused by labels or procedure declarations, or implicit such as those necessary in conditional statements or expressions, in the administration of for-statements or array declarations, and in evaluation of expressions as parameters.

A reference to a program point is stored in a comma-marked-instruction in the following way:

qq <trackrel>.19 + <trackno>.39 + <right>.41

where <right> = 1 (instruction f-marked) indicates that the program point is in the right-half-part of the word referenced and <right> = 0 indicates left-part.

References to implicit program points on the same track e.g. jumps in if-then-else-statements may be carried out by means of relative addressing. (cf. ref. j2-6)

Conditional jumps (ref. j3-6) to program points on other tracks are performed via a constant word containing an unconditional track jump (ref. j1)

<end track inf> ::= qq <track rel>.19 + <linecount mod 1024>.39 + <rigth>.41

ref.	instruction	meaning / used in	caused by dir. byte
j1	hs c2 , <program point>	unconditional track jump	eg.26,29,30,32
j2	hv/hh r <reladdr>	- local jump	eg.26,29,30,32
j3	hv/hh < - >	conditional - -	22,27
j4	hv/hh r < - >	- - -	23,28
j5	hv/hh r < - >	- - -	24
j6	hv/hh r < - >	- - -	25
j7	hs c1 , <end track inf>	exit to next track (normal mode)	
j8	hs c3 , < - >	- - - - (param. -)	
j9	hs c26 , <program point>	- - fast st.proc	9
j10	hvn c18	- from param. expr	19
j11	hvn c19	- - - -	19
j12	hv c18 *	- - subscr. param. expr	19
j13	hv c19 ⊕	- - - - -	19
j14	hv c21	- - type proc	17
j15	hh c22	- - no - -	16
j16	hs c9	- - block	18
j17	hhn c29 , <last line>	- - program	
j18	hs c14 X NZA	- to multiply [124]<--	48
j19	qq (c33), hs c39	- - outchar variable	60
j20	ud c37 , hs c37	- - next in (lyn) -->[c15]	46
j21	ncn (c30), hs c13	- - goto computed	42
j22	qq 64 , hs c39	- - write cr	41
j23	qq <10 bit const>, hs c39	- - outchar constant	108
j24	hs c4 , <program point>	- - ↑ integer/real	111,113
j25	is (c38), hv/hh s<rel addr>	- - block code on same track	10
j26	hh (c38),	- - - - in same word	10
j27	arn <op> , hs c20 *	- - reserve array (buffer m.)	96
j28	ud <op> , hs c28	- - move formal	101
j29	ud <op> , hs c8	- - take formal	102
j30	ud <op> , hs c25	- - controlled formal	103
j31	ud <op> , hs c24	- - assign to formal subscr.	104
j32	hs p<blockrel>	goto for label word in stack	34,35
j33	hv/hh s<reladdr>	for label word when jump is local	34,35

2.9.6. Block entries

A block is generated with the following format:

[b1]	qq <stack appetite>, hs c7	10
[b2]	hv c11 , hh <displ ref>	16,17,18
[b3]	<block parameters>	11,110
[b4]	<goto block code>	10

<block parameters> are references to explicite program points. They appear in the program in the opposite order of that in the Algol text. The possible parameter formats are described under reference p1-11 and j8.

<goto block code> is treated by RS as a parameter, but with one of the formats j1, j25 or j26.

2.9.7. Procedure calls

The format of a procedure call is the following

```
[pc1] qq <stack appetite>,  hs c7                                    6,7
[pc2] arn                ,  <program point> ; return information     14
[pc3] <call parameters>                                              19
[pc4] isf <displref>     ,  ps s <blockrel> ; exit call              7
```

<call parameters> are described under reference p6-17, p21-28 and j8

ref. c4 may be replaced by j1 if the call refers to a slow standard procedure.

2.9.8. Case administration

The format of the case-administration code is the following:

```
[cs1] qq <no of param>   , hs c15;  [f5]<--    [c15]<--        12,13
      <case error action>                                     12,13
      <goto end case>                                         12,13
      <case parameters>                                       20(+12)
```

<case error action> is either if the case administration appears as the body of a label procedure (switch)

```
[cs2] pa   c30                    ;   indicate dummy switch action

     else

[cs3] pt   c49-4 ,  hs c27        ;   exit to case error
```

<goto end case> is an unconditional jump (j1-2)

<case parameters> are described under reference p6-11, p18-20, p22 or may be a jump to evaluation of a case parameter expression local on the track:

```
[cs4] it   (c16) ,  hv/hh <reladdr>
```

2.9.9. Reference table

ref	instruction	meaning	Used in case adm.	Used in proc. call	Used in block entries
			X		
				X	
			X		
p1	qq , <programpoint>	label	X		
p2	zq , < - >	integer proc. with parameters	X		
p3	zqf , < - >	real - - -	X		
p4	zqn , < - >	boolean - - -	X		
p5	arn , < - >	label - - - (switch)	X		
p6	zqfn , < - >	no type expr. or proc.	X	X	X
p7	psn , < - >	integer - - - no param.	X	X	X
p8	psfn , < - >	real - - - - -	X	X	X
p9	qqn , < - >	boolean - - - - -	X	X	X
p10	qqf , < - >	label - - - - -	X	X	X
p11	qqfn , < - >	string - - - - -	X	X	X
p12	ps (<displref>) , it s<blockrel>	integer simple		X	
p13	psf (< - >) X <blockrel> NTB	real -		X	
p14	ps (< - >) , it n s<blockrel>	boolean -		X	
p15	psnf (< - >) X <blockrel> NQB	string -		X	
p16	psf (< - >) X < - > NQB	label		X	
p17	isf (< - >) , pmns<blockrel>	described in stack		X	
p18	is (< - >) , < - >	float simple			X
p19	is (< - >) , < - >	non float simple			X
p20	is (< - >) X <blockrel> NTB	label			X
p21	qq <arrayrel>.9+<doperel>.19+<no.of ind>.39	array: first paramword		X	
	psf (<displ ref>), hv c12	- : second paramword		X	
p22	<anything no marks>	constant value		X	X
p23	psn (c10) , it s<stackrel>	integer constant		X	
p24	psfn (c10) X < - > NTB	real -		X	
p25	psn (c10) , itns< - >	boolean -		X	
p26	ps <programpoint>	integer subscr. var		X	
p27	psf < - >	real - -		X	
p28	ps < - >	boolean - -		X	

Appendix 3: EXAMPLE OF TEST OUTPUT FROM GIER ALGOL 4

Below follows a small ALGOL program and the test output from the compilation. The first three lines from pass 1 are given exactly as they have been printed by the compiler; after this follows the whole test output with comments inserted below each line of bytes.

```
Demonstration of factorial
begin
integer procedure fact (n); value n; integer n;
fact:= if n < one then one else n × fact (n-one);
integer n, one;
one:= 1; writecr;
for n:= one step one until 10 do write (⟨ddddddd⟩, fact(n));
end
```

```
begin
1.   93  1010   116   137     6     1     3    20   184    14
    291   167   157    14   167   116    14   167  1010     6
      1     3    20   228   106    14   272    15    14     5
```

```
Demonstration of factorial
```

```
begin
1.   93  1010   116   137     6     1     3    20   184    14
   begin  CR integer proc     f     a     c     t     (     n

    291   167   157    14   167   116    14   167  1010     6
      )     ;  value     n     ;  integer n     ;    CR     f

      1     3    20   228   106    14   272    15    14     5
      a     c     t     :=  if     n     ≤     o     n     e

    231    15    14     5   176    14   267     6     1     3
   then     o     n     e  else     n     ×     f     a     c

     20   184    14    76    15    14     5   291   167  1010
      t     (     n     -     o     n     e     )     ;    CR

    116    14   220    15    14     5   167  1010    15    14
integer     n     ,     o     n     e     ;    CR     o     n

      5   228    58   167    23    18     9    20     5     3
      e     :=    1     ;     w     r     i     t     e     c

     18   167  1010    98    14   228    15    14     5   196
      r     ;    CR   for     n     :=    o     n     e  step

     15    14     5   198    58    57   243    23    18     9
      o     n     e until     1     0    do     w     r     i

     20     5   184  1013     0     0   476     0   220     6
      t     e     ( < literal    ⟨ddddddd⟩     >     ,     f

      1     3    20   184    14   291   291   167  1010   172
      a     c     t     (     n     )     )     ;    CR   end

   1009     0
endpass  fill
```

2.

```
 93    77   116   137  1021   184  1020   291   167   157
begin  CR integer proc fact    (    n     )     ;  value

1020   167   116  1020   167    77  1021   228   106  1020
  n     ;  integer  n     ;     CR  fact    :=    if    n

 272  1019   231  1019   176  1020   267  1021   184  1020
  ≤    one  then   one  else     n     ×  fact     (    n

  76  1019   291   167    77   116  1020   220  1019   167
  -    one    )     ;     CR integer  n     ,    one    ;

  77  1019   228    58   167  1018   167    77    98  1020
  CR   one    :=     1    ;  writecr    ;     CR   for    n

 228  1019   196  1019   198    58    57   243  1017   184
  :=   one  step   one  until     1     0    do write     (

  80     0     0   476     0   220  1021   184  1020   291
 < literal  ⟨ddddddd⟩     >     ,  fact     (    n     )

 291   167    77   172   283     0
  )     ;     CR   end endpass fill . . .
```

3.

```
   0       6    1017      31    1018   1016      20       0       0    1021
endpass 6.std.=write  31.std.=writecr free id.  begin     CR      CR    fact

  43    1020      57      30    1021     77     129    1020     493    1019
declare    n  spec.int. end.sp.  fact     :=   ifex       n       ≤     one

 131    1019     132    1020     146   1021      39    1020     145    1019
thenex    one  elseex       n       ×   fact beg.func.       n       -     one

  31     134      75       1      19      0    1020    1019       5       0
endcall endelseex endass. <1, endtypeproc> CR       n     one declare      CR

1019      77       0       0       0       1       1      75      21    1018
 one      :=       <       constant =      1       >  endass.       ;  writecr

 128      21       0     138    1020      71    1019     139    1019     140
proc;      ;      CR     for       n   :=for     one    step     one   until

   0       0       0      10       1     163      22    1017      38       0
   <          constant = 10          >  stepdo      do   write beg.call       <

   0     476       0       3      34    1021      39    1020      31      31
     constant = ⟨ddddddd⟩     >    call,  fact beg.func       n endcall endcall

 133     142      21       0      16       0
deletecall enddo    ;      CR endblock  fill . . .
```

```
4.    2       17        0      142      133      177      177     1020        1        3
    endpass endblock    CR     enddo deletecall endcall endcall   n     <1, beg.func.>

     1021     180       0      476       0        0       86       2       22      1017
     fact      ,        <          constant = {ddddddd}     >  <2, beg.call.>   write

      172     163       10       0       0        0       84      140     1019     139
       do    stepdo     <          constant = 10          >   until     one     step

     1019     185      1020     138       0      128     1018     189       1       0
      one    :=for      n       for      CR     proc; writecr  endass.     <

        0       0       84     193      101     1019       0       15     1019    1020
   constant = 1          >   prepass.   :=      one       CR     endhead  one      n

        0     195        1      19      189      134     177     1019     145     1020
       CR bypas lab.     <    (1)     > endass. endelseex endcall  one      -       n

        1       3      1021     146     1020      132     1019     131     1019     493
    <1, begfunc>       fact      ×       n      elseex    one     thenex   one      ≤

     1020     129      193      101     1021       15      16     1020      68     1021
       n      ifex   prepass.   :=     fact    endhead enddecl.    n      value    fact

      195    1023     1023      37     1021        0       0       16     1021      48
   bypass lab. <        (2)      >     fact       CR      CR     enddecl  fact      decl

     1018      20      1020     1019       52     1021    1023     1016     1017     1020
   int.val.   spec.     n       one    decl.int.  <                 (3)

        2       0
        >     fill . . .
```

Notes: Read the output from pass 4 backwards
(1): Number of parameters, end type proc.
(2): Base working locations, base variables, begin integ. proc. with params.
(3): These 6 bytes are:
base working locations outermost block
base variables - -
free identifier
standard identifier having lowest std. ident. no. in output pass 3
1021 - maximum block number - number of owns = relative stackref. 0
2 + number of owns.

```
5.  1020     197    1021     196     196     198    1021    1023     195     445
     sr0  <beg.block, basew>  CR      CR  <beg.proc, int., basew>  byp.lab.  <

      2    1023     200     444    1023    1023     191     193     129     444
      n       >   value       <    fact       >      :=  prepass.  ifex     <

      2    1023     493     444    1022       0     131     444    1022       0
      n       >      ≤        <     one       >  thenex       <     one       >

    132     444       2    1023     146     440    1023       0     477     214
 elseex       <       n       >       ×       <    fact, integ.val.    > <begfunc.

      1     444       2    1023     145     444    1022       0     177     134
  , 1 >       <       n       >       -       <     one       > endcall endelseex

    189     206       1     195     196     196     444    1022       0     191
 endass. <endtypepr, 1>  byp.lab.      CR      CR       <     one       >      :=

    193     468       0       0       0       1     189    1020     128     196
 prepass.  <          constant = 1                  >  endass. writecr  proc;    CR

    138     444    1021       0     185     444    1022       0     139     444
    for       <       n       >   :=for       <     one       >    step       <

   1022       0     140     468       0       0       0      10     163     172
    one       >   until       <          constant = 10          >  stepdo      do

   1018     208       2     470       0       0     476       0     180     440
  write  <begcall, 2 >       <          constant = ddddddd       >    call,     <

   1023       0     477     214       1     444    1021       0     177     177
   fact, integ. val.   > < begfunc., 1>       <       n       > endcall endcall

    133     142     196     204     213       5    1020      12      11      10
deletecall enddo      CR  endblock < endpass, 5,  sr0, include std.tracks 12, 11

      9       0
  10, 9 >  fill . . .
```

Identifiers in output from pass 5:

	kind-type	rel. addr.	block	specs
fact (as proc):	440=int.proc.w.par.	-1	0	int.val.
n (in block):	444=simple int.	-3	0	
one:	444 -	-2	0	
fact (as val.):	444 -	-1	1	
n (in fact):	444 -	2	1	

writecr: 1020
write: 1018

```
6.  1020      5    1021     96      96      2    1021    1023     86      71
     sr0  <beg.block,basew>  CR      CR  <beg.proc., int, basew> byp.lab.  <

      2    1023     84      71    1023    1023    116      10      71       2
      n       >   value     <     fact       >  address    if      <       n

   1023      71    1022       0      55      71    1022       0      37       1
      >      <     one         >   <then      <     one         >   < else int.>

      71       2    1023      73    1023       0       0      71       2    1023
      <        n       >      <     fact       >  begcall     <        n       >

      71    1022       0      46      78       1       1      47      39       1
      <     one         >      -   < param,  , int.> endcall ×int.  <endelse, int.>

      42      43       4       1      86      96      96      71    1022       0
  prepass.    :=  <endtypepr., 1> byp.lab.   CR      CR      <     one         >

     116      75       0       0       0       1      42      43     106      30
  address     <          constant = 1            >  prepass.    :=  writecr  proc;

      96      13      71    1021       0      14      71    1022       0      20
      CR     for      <       n         >   :=for     <     one         >   step

      71    1022       0      21      75       0       0       0      10      23
      <     one         >   until     <          constant = 10            >   stepdo

      74    1020       0       0      75       0       0     476       0      78
      <    write        >  begcall    <       constant = {ddddddd}       >   <param

       3      73    1023       0       0      71    1021       0      78       1
  , bool.>    <     fact         >  begcall     <       n         >   <param, int.>

       1      78       1       1      36      77      96       6      87       5
  endcall  <param, int.> endcall proc;   enddo    CR   endblock  <endpass, sr0

    1020      12      11      10       9       0
  , include std. tracks 12, 11, 10, 9 >    fill . . .
```

Identifiers in output from pass 6:

```
fact (as proc):  proc.,  reladdr.,  block
fact (as var),
n, one         :  simple,    -         -
writecr        :  106
write          :  std.proc,  trackno.,  reladdr.
```

```
7.  116      10      112      112     1021       11       31       2        1      102
    endpass begblock CR       CR     <int., begproc> byp.lab.  <      n      formal>

      2       1       70       39       2       1      124      21     1022       2
      <       n      M:=>     intval.   <       n      :=R>     if     <        one

    121       2       1      123       23    1022       2      121       1       32
    R:=>      <       n       R- >     goif-  <        one     R:=>      <int.  else>

      2       1       70     1022       1      71     1023       0       7       2
      <       n      M:=>     <         w1     :=M>    <       fact    begcall>  <

      1     121     1022       2      123       0       5     124       0       5
      n     R:=>    <         one     R- >      <      UV     :=R>      <      UV

      1      19       0      14        0       5      70     1022       1      93
    int.  param>  <0 lits. endcall>   <      UV     M:=>    <         w1     int.

     48       1      33     1023       1     124       1     109     1020    1023
    mult>    < int. endelse>  <       fact    R:=>     < 1 formal, appetite, block

     17      31     112      112       0       0       0       0       8      70
  endproc> byp.lab.  CR       CR       <          constant = 1                M:=>

   1022       2      71       41      112      21    1022       2      70    1021
   <         one     :=M>   writecr    CR      for    <        one    M:=>   <n:=

      2      91    1020        1       36      31    1022       2     121    1021
  M; first:= true>  <         w2     forlab.> byp.lab. <        one   R:=>    <

      2     122    1021        2      128    1021       2      94       10       0
      n      R+>   <if-,first then n:=R>   <else first:= false>      <

      0       0       8     121    1021       2     123    1022       2      75
    constant = 10           R:=>   <         n      R->     <        n    xsig( >

     28      31    1020        0       6       0     476       0       0       8
  goenddo- byp.lab.  <       write  std.cal>    <        constant = {ddddddd}

      3      19    1023        0       7    1021       0       9       1      19
   bool.  param>    <        fact   begcall>  <         n     simple   int    param>

      0      14       0        5       1      19       1      14    1020       1
  <0 lits. endcall>  <       UV       int    param>  <1 lit endcall> <        w2

     35     112    1018        0      18    1020      12      11      10       9
   enddo>    CR   <appetite block endblock> < sr0  include std. tracks 12, 11, 10

      5       0
    , 9>    fill . . .
```

Variables in output from pass 7:

```
n (in fact):    relative 2,   local block
one:                 -  -2,   outermost block
w1:                  -  -2    local block
fact (proc):         -  -1,   block 0
UV:                  -   0,   UV cells
fact (val.):         -  -1,   local block
n (in block):        -  -3,   outermost block
```

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